Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Correlation analysis of solar constant, solar activity and cosmic ray

To cite this article: Y S Utomo 2017 *J. Phys.: Conf. Ser.* **817** 012045

Correlation analysis of solar constant, solar activity and cosmic ray

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Abstract. Actually, solar constant is not constant but fluctuated by ±1.5% of their average value. Solar constant indicates that the value is not constant but varies with time. Such variation is correlated with solar activity and cosmic ray. Correlation analysis shows a strong correlation between solar activity and cosmic ray and between solar activity and solar constant. Solar activity indicates by sunspot number. Correlations between solar constant variations and sunspot number variations were found to be higher than ones between variations in cosmic ray and solar constant. It was also found a positive correlation between solar constant and sunspot number, with correlation coefficient about +0.77/month and +0.95/year. In other hand, negative correlation between solar constant and cosmic ray flux i.e. −0.50/month and −0.62/year were found for monthly and yearly data respectively. A similar result was also found for the relationship between solar activity and cosmic ray flux with a negative correlation, i.e. −0.61/month and −0.69/year. When solar activities decrease, the clouds cover rate increase due to secondary ions produced by cosmic rays. The increase in the cloud cover rate causes the decrease in solar constant value and solar radiation on the earth's surface. Solar constant plays an important role in the planning and technical analysis of equipment utilizing solar energy.

1. Introduction

The sun is the main energy source for the earth and its environment. Through the emitted energy, the sun acted as a climate controller is very important to the air movement (atmospheric circulation) and ocean currents (ocean circulation) as well as to bio-instruments that processes photosynthesis in the biosphere. Therefore, the climate also depends on variations in the flux of solar energy received by the earth's surface. Variation in the solar energy flux is caused by variations in solar activity cycle. Thus the climate is a manifestation of how solar radiation is absorbed, redistributed by the atmosphere, land and oceans, and ultimately radiated back into space. Every variation of solar energy received at the earth's surface and reradiated by the earth into space will have a direct impact on climate change on Earth.

When reaching the upper limit of the atmosphere, the solar radiation is not actually attenuated but when it passes through the layers of the Earth's atmosphere solar radiation it will be scattered and absorbed by molecules and particles of dust clouds. Thus, only a small fraction of the solar radiation reaches the earth. Radiation flux before attenuation by the atmosphere at an average distance of the Sun - Earth (1.5×10^8 km) is called the *solar constant* which is defined as the total amount of solar radiation of all wavelengths, which falls on a unit area of the surface normal to the Sun - Earth line on a clear sky condition [1].

Solar activity was also influenced by variations in solar irradiance received at the earth's surface. Simulation of solar irradiance variability over 113 years (1880-1993) showed a variation of 0.5 %. While satellite observation during one cycle showed a variation of 0.1 % between the minimum and maximum activity [2, 3]. Determination of the solar constant and its variations over time is needed in climate research [4]. Solar constant plays an important role in the planning and technical analysis of equipment utilizing solar energy [5].

The results of this study are expected to use as an input and consideration in the planning and technical analysis of renewable energy, in particular the utilization of solar energy will be intensified and expanded in line with increasing energy needs. The utilization of solar energy is one step in the development of energy diversification. However its field operations should be supported with adequate information about the potential and availability of solar energy at a given location. By knowing the potential and availability of solar energy, then the site selection mistakes can be avoided.

2. Basic Theory

2.1. Solar Constant

Solar constant is defined as the total amount of solar radiation of all wavelengths, which falls on a unit area of the surface normal to the sun - earth line on a clear sky condition [1]. Until now, the absolute value of the solar constant uncertainty is both theoretically and observationally high enough. Determination of the solar constant has experienced a long history, has began by Smithsonian Institute in the early 20th century [6]. Solar constant measurement data obtained at that time were large, but the results did not provide a convincing value of solar constant [7].

The average value of solar constant ranges from 1364.61 to 1371.67 Wm^{-2}. Nimbus-7/ERB measurement is differed by 4.31 to 6.86 Wm^{-2} compared to the three other measurement results. It is caused by the problem of directing the telescope, correction calculation the average distance of the earth-sun and the sensitivity of instruments. Sensor Nimbus-7/ERB has an accuracy of 0.5 Wm^{-2} [8].

2.2. Solar Activity

Fluctuation of turbulence in the surface of the sun is related to the term of what we called as a solar activity. The combination of radiation activity and magnetic activity plays a major role in the cycle of solar activity. One indicator of solar activity is the appearance of black spots on the sun's surface called sunspots. The numbers of sunspots indicate the activity level of the sun. Variations in solar activity can affect the geomagnetic properties of ionosphere and stratosphere layer. Rapid changes in the region of UV radiation and X-rays due to solar activity can affect the ionosphere and the atmosphere through a system of coupling the magnetosphere-ionosphere-atmosphere [9, 10].

Solar activity was also influenced by variations in solar irradiance received at the Earth's surface. Simulation of solar irradiance variability over 113 years (1880-1993) showed a variation of 0.5%, while satellite observation during one cycle showed a variation of 0.1% between the minimum and maximum activity [2, 3]. Determination of the solar constant and its variations over time is needed in climate research [4]. Solar constant plays an important role in the planning and technical analysis of equipment utilizing solar energy [5].

2.3. Cosmic Ray Flux

Cosmic rays are energetic particles originating from space and spread until it reaches the Earth's atmosphere equal in all directions. The composition of cosmic rays consists of protons (90%), a helium nucleus (9%) and electrons (1%). Cosmic rays or the full name of Galactic Cosmic Rays (GCR) has a high energy level in the range of 300 MeV to 10 GeV. The main cause modulation of the cosmic rays is not the activity level of the sun, but the variation in the magnitude of the solar wind. The amount of solar wind is not constant, but varies with changes in solar activity during the 11 annual cycles [11].

Cosmic ray particles that had such high energy enter the Earth's atmosphere at speeds approaching 3×10^8 m.s^{-1}. With this speed and high energy, the cosmic ray particles are possible to collide with molecules of atmospheric when cosmic rays entering Earth's atmosphere. This collision is able to break the composition of the molecules in the atmosphere and induced the formation of secondary ions which serve as condensation nuclei to increase the formation rate of high clouds (at an altitude of 12-15 km). Because cosmic rays have an impact on the formation rate of cloud which further affects the amount of solar radiation to reach the Earth's surface, the contribution of cosmic rays on the Earth's climate cannot be ignored [11].

2.4. Correlation between Solar Constant, Solar Activity and Cosmic Ray Flux

Solar Constant is actually not constant but fluctuated by ±1.5% of their average value [1]. Direct observation via satellite indicates the same that the solar constant value is not constant but varies with time. The variation of solar constant that occurs as a result of changes in the form of solar activity such as sunspots dark or faculae bright in the Sun's surface [4, 10].

Solar activities have close correlation with the solar constant whose inconstant values. Therefore, in addition the sunspots, faculae are also an important source of solar constant variations [10]. The amount of solar energy emitted from the entire surface of the Sun is not the same, but varies with time. Hoyt and Kyle studies (1990) indicated that the solar constant will decrease with an increase in the sunspot area and will increase with the presence of the excellent faculae area on the solar disc. Based on Lean's research (1991) solar constant value at the time of minimum solar activity in 1986 is about 1367±3 Wm^{-2}, and showed a variation of 0.1% [2, 8].

3. Methodology

To determine whether there is a relationship between solar constant and solar activity, in this study the effect of solar activity (with indicators of the sunspot numbers) on the solar constant were analyzed using data with a 39-year period (1978-2016). Daily data for global solar constant were obtained from ftp://ftp.ngdc.noaa.gov/STP/solar_data/solar_irradiance/composite_42_65_1611.dat. Daily data of solar constant were processed into monthly average data, and then compared to monthly average data of sunspot numbers, which were obtained from ftp://ftp.ngdc.noaa.gov/STP/solar_data/sunspot_numbers/ridaily.plt with a 39-year period (1978-2016). These data were used in the analysis of solar activity's influence on the solar constant variation. Monthly Cosmic rays data (Galactic Cosmic Rays - GCR data) were obtained from ftp://ftp.ngdc.noaa.gov/STP/solar_data/cosmic_rays/huancayo.dat with a 39-year period (1978-2016). Furthermore, correlation analysis using a linear regression to determine the degree of influence of solar activity on the solar constant was employed and the effect of cosmic rays on the solar constant variation and its relation to solar activity was studied. In correlation analysis, it can be estimated a sample correlation coefficient which is denoted by r, ranges between –1 and +1. This coefficient quantifies the direction and strength of the linear association between the two variables. The correlation between two variables can be positive or negative. The sign of the correlation coefficient indicates the direction of the association. The magnitude of the correlation coefficient indicates the strength of the association.

4. Analysis and discussion

4.1. Correlation analysis

As already known, that the value of the solar constant is not constant, but varies with time despite minor amendments. The change might be related to solar activity and cosmic rays. Therefore, all three parameters i.e. solar constant, solar activity (which is indicated by the number of sunspots) and cosmic rays) have a relationship or correlation between one parameter with another. Correlation analysis was done by calculating the correlation coefficient and the results are summarized in Table 1.

Table 1 shows the correlation coefficient both per month and year between solar constant, sunspot number and cosmic rays. The values are all above ±0.50 which can be categorized as high value. The high correlation coefficient indicates that cosmic rays and sunspot numbers have strong relationships with the solar constant. There are two types of correlation between the solar constant with both parameters, namely the positive and negative correlations. The correlation coefficient between the solar constant and sunspot numbers are very high with positive number, i.e. +0.77/month and +0.95/year. The correlation coefficient between the solar constant and cosmic rays is high with negative number, i.e. –0.50/month and –0.62/year, while the correlation coefficient between sunspots number and cosmic rays were –0.61/month and –0.69/year. Therefore, if the value of cosmic rays increases then solar activity decreases, indicated by the reduction in sunspot numbers and the solar constant value.

Table 1. Correlation between solar constant, sunspot number and cosmic rays.

Parameter Relation	Correlation coefficient - *r*	
	per month	per year
Solar Constant – Sunspot Number	+0.77	+0.95
Solar Constant – Cosmic Rays	–0.50	–0.62
Sunspot Number – Cosmic Rays	–0.61	–0.69

The influence of solar activity on the solar constant variation has been proposed by previous researcher [2, 3]. A previous researcher simulated the variability of solar irradiance over 113 years (1880-1993) and found the variation of solar constant at 0.5% [2], while another researcher found a variation of 0.1% based on satellite observations during a solar cycle, i.e. the 21th cycle (1976 to 1986) [3]. Determination of the absolute value of the solar constant and its variations over time is needed in climate research. Solar constant plays an important role in the planning and technical analysis of equipment utilizing solar energy. Another researcher reported a correlation between temperature and global cloud coverage with the cosmic rays [12]. The influence of cosmic rays on cloud coverage, could also affect the solar constant [4, 5].

4.2. Influence of solar activity on the solar constant

For purposes of analysis influence of solar activity on the solar constant, the daily data of solar constant and solar activity in the period of November 1978 to November 2016 were used. Solar activity is indicated by the number of sunspots.

Figure 1 shows the pattern of the yearly average value of solar constant is similar with the pattern of the yearly average number of sunspots. The figure also shows the 21th solar cycle (1976-1986) and the 22th cycle (1987-1997). In the 21th solar cycle, the yearly average value of the solar constant reached its maximum value of 1366.56 Wm^{-2} in 1979. This coincided with the peak period of 21thsolar activity cycle which reached the maximum yearly average sunspot number of 155.3. Start from 1980, the value of the solar constant was gradually reduced following the reduction in solar activity. Solar constant value reached minimum when the sun was quiet in 1985-1986 with the average value of 1365.54 Wm^{-2}. The lowest value occurred in 1986, i.e. 1365.54 Wm^{-2} in conjunction with solar activity reached a minimum value. At the beginning of 22th solar cycle (1987–1997), a constant value increases exponentially with the increment of solar activity. The sun reaches its maximum solar constant value in 1989 with the amount of 1365.39 Wm^{-2} in conjunction with solar activity reached its maximum with yearly average sunspot number of 157.8. Solar constant value remained high during the years of 1989-1992 with small variations from year to year ranged from 0.04 to 0.32 Wm^{-2}. When the 23th solar cycle began in 1998, the value of the solar constant grew significantly following the increase in solar activity which was peaked in 2000. The yearly solar constant values were ranging from 1365.43 to 1366.60 Wm^{-2} or varied by 0.09% against the average value of 1366.01 Wm^{-2} [10, 13–15].

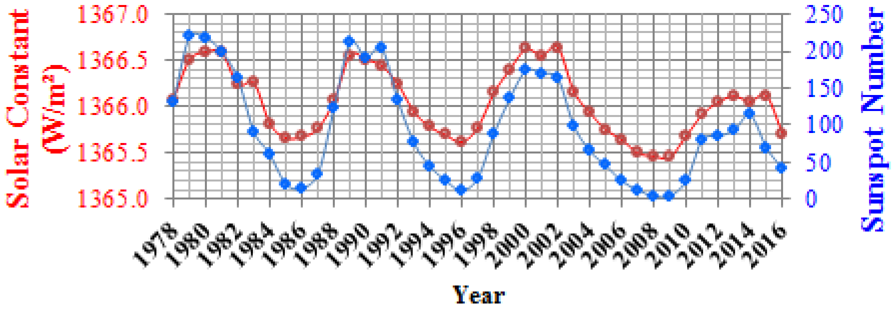

Figure 1. Yearly average of solar constant and sunspot number.

4.3. Influence analysis of cosmic ray on the solar constant

For the influence analysis of cosmic rays on the solar constant, the daily average cosmic ray data of Huancayo, Peru (12^o S, 75^o W) and solar constant data in the period of November 1978 to November 2016 were used. Huancayo was chosen with consideration that it has the lowest latitude among several other locations on Earth. Figure 2 shows the effect of cosmic rays on the solar constant.

Figure 2 shows yearly averages of solar constant and cosmic rays which has the same pattern but in the opposite direction. Yearly average of solar constant variation cycle was seemed to follow the cycle of the yearly average variation of cosmic rays in the opposite direction. When cosmic rays increased, the solar constant actually declined. As mentioned before, cosmic ray particles that have high energy (10 GeV) enters the Earth's atmosphere at speed approaching to 3×10^8 ms^{-1}. With its high speed and high energy, it is possible to collide with molecules of atmospheric and to break the composition of the molecules in the atmosphere forming the secondary ions which acts as condensation nuclei. The increase in the formation rate of cloud would affect the decrease in the intensity of solar radiation reaching the Earth's surface. The relationship between cosmic rays and solar constant is a "opposite" relationship because of the negative correlation type ($r < 0$). The phenomenon of "opposite" is in a good agreement with the result by Svensmark (1997) who found a correlation between temperature and global cloud coverage with the cosmic rays [12].

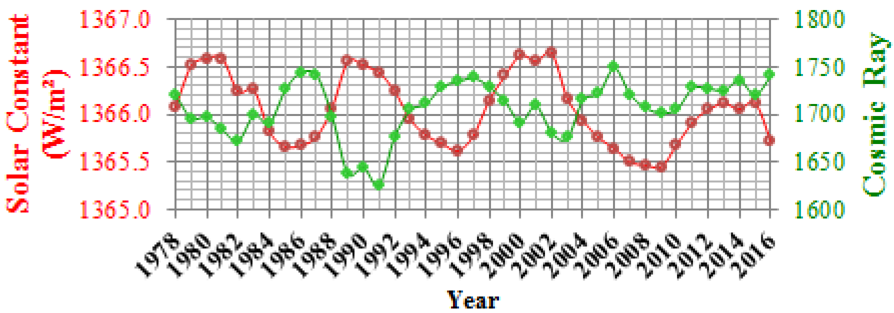

Figure 2. Yearly average of solar constant and cosmic ray.

4.4. Influence analysis of solar activity on the cosmic ray

For the influence analysis of the of solar activity on cosmic rays, a daily average of cosmic rays and sunspot numbers data during the period November 1978 to November 2016 were used. Figure 3 shows the effect of solar activity on cosmic rays.

In figure 3, variation of yearly average cosmic rays is in opposite to the pattern of sunspot numbers. When solar activity is maximum (indicated by the high number of sunspots), cosmic rays is minimum.

This phenomenon of "opposites" is in accordance with what is stated by Svensmark (1997) who found a correlation between temperature and global cloud coverage with the cosmic rays. Physically, particles of cosmic rays when it enters the Earth's upper atmosphere are suffered from modulation caused by two things, namely the solar wind and Earth's magnetic field. The solar wind affects cosmic ray particles to decelerate. According to Yamada (1998), the size of the solar wind is not constant, but varies with changes in solar activity during the 11st annual cycles. The relationship between solar activity and cosmic rays is an "opposite" relationship because of negative correlation type ($r < 0$). The solar activity influenced on cosmic rays has an impact on the cloud formation rate [11, 12].

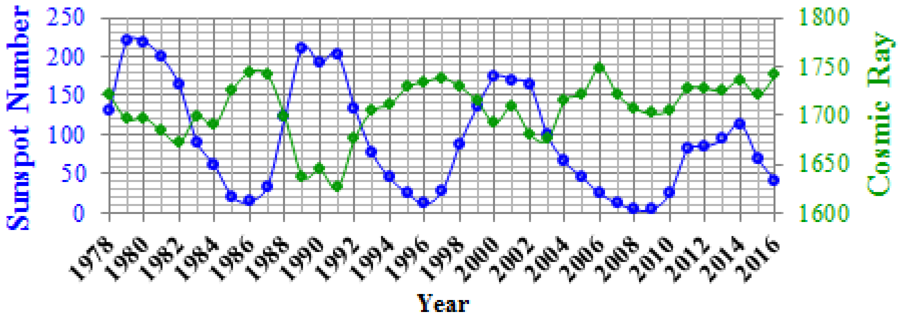

Figure 3. Yearly average of sunspot number and cosmic ray.

5. Conclusion

Correlation analysis showed that there was a relationship between the variation of the solar constant with the variation in solar activity and the flux of cosmic rays. A positive correlation (r = 0.95) was found between the solar constant and solar activity, a negative correlation (r = –0.62) was for the relationship between the solar constant and cosmic rays, and also a negative correlation (r = –0.69) between solar activity and cosmic rays.

The results of this study are expected to be used in the consideration in the work of planning and technical analysis of renewable energy, particularly in the utilization of solar energy that will be intensified and expanded in line with increasing energy needs. The utilization of solar energy is one step in the development of energy diversification, but its application should be supported with adequate information about the potential and availability of solar energy at a given location. By knowing the potential and availability of solar energy, mistake in choosing the site selection can be avoided.

Acknowledgments

The author gratefully acknowledgment the support of the Research Center for Electrical Power and Mechatronics, Indonesian Institute of Science (LIPI) for funded and has given encouragement and opportunity to work in the field of conversion and conservation energy research.

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